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Psychological factors influencing sustainable energy technology acceptance: A review-based comprehensive framework

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ABSTRACT

Environmental and societal problems related to energy use have spurred the development of sustainable energy technologies, such as wind mills, carbon capture and storage, and hydrogen vehicles. Public acceptance of these technologies is crucial for their successful introduction into society. Although various studies have investigated technology acceptance, most technology acceptance studies focused on a limited set of factors that can influence public acceptance, and were not based on a comprehensive framework including key factors influencing technology acceptance. This paper puts forward a comprehensive framework of energy technology acceptance, based on a review of psychological theories and on empirical technology acceptance studies. The framework aims to explain the intention to act in favor or against new sustainable energy technologies, which is assumed to be influenced by attitude, social norms, perceived behavioral control, and personal norm. In the framework, attitude is influenced by the perceived costs, risks and benefits, positive and negative feelings in response to the technology, trust, procedural fairness and distributive fairness. Personal norm is influenced by perceived costs, risks and benefits, outcome efficacy and awareness of adverse consequences of not accepting the new technology. The paper concludes with discussing the applicability of the framework.

Contents

1. Introduction

Worrisome environmental and societal problems related to energy use (e.g., acid rain, air pollution, ozone depletion, climate change and fossil fuel dependency) have spurred the development of more sustainable energy technologies. While some

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technologies are implemented rather seamlessly in society (e.g., energy efficient boilers, compact fluorescent lamps, ozone free cooling systems in fridges, soot filters, and solar panels), other technologies have encountered diverse amounts of resistance from the public (e.g., wind mills, carbon capture and storage installations, hydrogen refueling stations, and nuclear power plants). The resistance can result from perceived hindrance and safety risks, but resistance can also arise because people think that collective resources could have been spent in a better way, or the cost-benefit ratio is too low. Public resistance to the technology can hinder the implementation of sustainable energy technologies [43,57], which hampers the attainment of important environmental and societal goals. It is important to understand how people form an opinion on more sustainable energy technologies and why people take action in favor or against such technologies, as this yields important insights in how the design of the technology or the way the technology is implemented should be adapted, and how the technology should be communicated, such that the acceptance of the technology increases and its implementation is more successful.

Although many studies have shed light on psychological factors influencing technology acceptance, most studies focused on a limited set of psychological factors, and did not include a comprehensive set of key factors influencing technology acceptance. Understanding which key psychological factors influence technology acceptance, and how these factors are related, can help to improve the design of the technology, communication to citizens, and implementation of the technology.

To the best of the authors' knowledge, no comprehensive framework for sustainable energy technology acceptance has yet been proposed. This paper aims to develop a framework for technology acceptance that can be applied to new energy technologies (new as perceived by consumers and citizens; this does not necessarily mean new to experts or policy makers) designed or implemented to improve social and/or environmental conditions. The model focuses on psychological factors that influence attitudes (acceptability) and behaviors (acceptance) in favor or against technologies. The relevance of the factors in the model will be supported by empirical results on energy technology acceptance. The causal order of the factors will also be indicated, clarifying direct, indirect or moderating effects of the factors on technology acceptance.

We first clarify the key concepts acceptance and acceptability. Next, we discuss three types of motives and related psychological theories that underlie behavior in favor or against technologies. Subsequently, we elaborate on psychological factors that indirectly influence technology acceptance. These factors are related to evaluations of the specific design of a technology (viz. the attributes of the technology), the location of the technology (e.g., leading to specific distributions of costs, risks and benefits across people), and the actors involved with the introduction of the technology. We summarize relevant empirical evidence on the significance for each factor. Finally, we will present a comprehensive framework including factors that directly and indirectly affect technology acceptance, and discuss the applicability of this framework.

2. Acceptance and acceptability: definitions and focus

Several terms are frequently used in technology acceptance research, such as acceptability, support, adoption and attitudes (see [21], for an overview for terminology use in studies on hydrogen technology acceptance). In this paper, we define *acceptance* as behavior towards energy technologies and *acceptability* as an attitude (an evaluative judgement; [11]) towards new technologies and attitude towards possible behaviors in response to the technology [21].

Acceptance reflects behavior that enables or promotes (support) the use of a technology, rather than inhibits or demotes (resistance) the use of it. Support can be expressed in proclaiming the technology (for example because of its environmental benefits), or purchasing and using the technology. Resistance can be expressed in taking protesting actions against the technology, or not purchasing and using the technology. When people are in favor but do not take action against it, it can be said that people tolerate a technology. Connivance means that people oppose the technology but do not take action (see Deathloff, 2004, in [43]).

In this paper, we distinguish two types of acceptance (and acceptability): citizen and consumer acceptance. We define citizen acceptance as behavioral responses to situations where the public is faced with the placement of a technological object in or close to one's home, which is decided about, managed or owned by others [57,21,51]. An example of citizen acceptance is the public's response to build a hydrogen refueling station or a nuclear power plant. Consumer acceptance reflects the public's behavioral responses to the availability of technological innovations, that is, the purchase and use of such products. Examples are the purchase and use of solar panels or hydrogen vehicles. In the role of consumer, people can choose whether or not to be in contact with the technology and have more freedom and control than people in the role of citizen (see also p.11 [31]). Socio-political acceptance is a third type of acceptance, and involves people's responses to regional, national or international events or policy making that is not necessarily affecting their own situation or their backyard, or not affecting the availability and costs, risks and benefits of consumer products they would themselves want to use. We will not further discuss this type of acceptance in this paper.

3. Motives or goals influencing acceptance

Acceptance is motivated by different goals or end-states towards which people strive. Lindenberg and Steg (p. 119) [25], explain that goals influence decision making: "goals govern or 'frame' what people attend to, what knowledge and attitudes become cognitively most accessible, how people evaluate various aspects of the situation, and what alternatives are being considered." They distinguish three important motives or goals that influence behavior: gain, normative, and hedonic goals. When a gain goal is focal, individuals base their choice by weighing the costs, risks and benefits of options, and will choose options with the highest gain against the lowest costs or risks. When normative goals are focal, individuals base their choice on moral evaluations, that is, on what is deemed to be the most appropriate in that situation. When hedonic goal are focal, individuals base their decision on what feels best. When it comes to certain technologies, individuals can thus base their acceptance on (1) the overall evaluation of costs, risks and benefits, (2) moral evaluations, depending on the extent to which the technology has a more positive or negative effect on the environment or society and (3) on positive or negative feelings related to the technology, such as feelings of satisfaction, joy, fear or anger.

These three goals coincide with different psychological theories. The theory of planned behavior [2], for example, assumes that people make rational choices, evaluating and weighing perceived positive and negative expected outcomes, and thus focuses on gain goals. The norm activation theory [41] assumes that people act on feelings of moral obligations, based on values that they endorse, and thus focus on normative goals. Finally, theories on affect focus on the role of feelings, and thus focus on hedonic goals. In the next sections, we briefly explain these three theories and elaborate on relations between the three types of motives.

3.1. Gain motives and the theory of planned behavior

The theory of planned behavior (TPB [2]) proposes that intention to behave captures the motivation to exert a certain behavior and influences behavior. Intentions are based on outcome evaluations (attitudes and subjective norms) and perceived behavioral control. Attitudes towards the behavior refer to the degree to which a person has a favorable or unfavorable evaluation of the relevant behavior, based on the likelihood that a behavior has particular outcomes, and the evaluation of the importance of these outcomes [2,3,17]. Subjective norms refer to perceived social pressure to perform or not perform the behavior. Perceived behavioral control refers to the perceived ease or difficulty of performing the behavior [2].

Outcomes that influence attitudes and indirectly intentions to act in favor or against a technology can be divided into costs, risks and benefits. Costs of the technology can include personal financial costs such as the costs of purchasing or using the technology or societal costs such as subsidies needed to make the initial investments cost effective. Non-monetary costs are for example effort needed to understand or use the technology. Risks can include safety risks or uncertain financial costs, such as uncertain repair and maintenance costs. Benefits of the technology can relate to collective benefits, such as a reduction of environmental problems and energy security problems, but can also comprise personal benefits such as the easy access to the technology and improved (local) environmental conditions. Of course, only perceived and salient costs, risks and benefits will influence attitude at a specific moment [2]. Empirical studies should clarify which specific beliefs are salient with respect to a certain technology and to what extent they influence attitudes.

Two types of attitudes [5] are related to the acceptance of a technology: attitudes towards the technology as such, referred to as global attitude by Ajzen and Gilbert Cote [5], and attitudes towards a specific behavior in response to the availability or implementation of the technology, such as attitudes towards purchasing the technology or attitudes towards protesting against the technology. While attitude towards the technology gives the best prediction of a group of behaviors related to that technology, attitude towards a specific behavior gives a better prediction of the intention to perform that specific behavior and the actual performance of that specific behavior [5,4]. In the technology acceptance framework we will not specify type of attitude. A summary of the theory of planned behavior adapted for the technology acceptance model is depicted in Fig. 1.

The theory of planned behavior has been applied to predict technology acceptance. For example, Fox-Cardamone et al. [18] found that attitudes were predictive of antinuclear activism intentions. More specifically, both the evaluation of nuclear energy and the evaluation of anti-nuclear behaviors predicted intentions to seek information about an antinuclear group and donating time and money to an antinuclear group. Subjective norms (defined by Fox-Cardemone as "perceptions of social support for taking antinuclear action") and perceived behavior control (defined as "belief that collective action influences the use of nuclear energy" which is more similar to the meaning of outcome efficacy in norm activation theory) were not related to intentions when attitudes were controlled for. Molin [29] found that attitude towards the use of hydrogen predicts willingness to use hydrogen technologies.

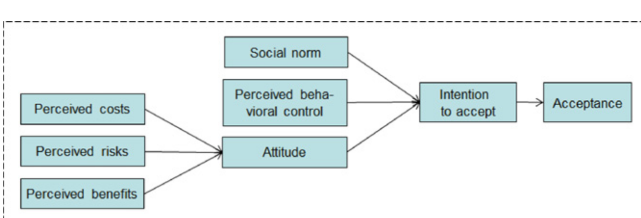

Fig. 1. The theory of planned behavior [2,3] adapted to technology acceptance.

A study on information technology acceptance tested a modified version of the theory of planned behavior (the unified theory of acceptance and use of technology [55]) and found that performance expectancy (viz. "degree to which an individual believes that using the system will help him or her to attain gains in job performance"), effort expectancy (viz. "degree of ease associated with the use of the system"), and social influence (viz. "degree to which an individual beliefs that important others believe that he or she should use the new system") influenced intentions to use the information technology by employees in a company.

Studies on the acceptance of carbon capture and storage [28] and gene technology [26] showed that perceived risks and benefits of these technologies indeed predict the attitude towards the technology. Stated preference studies showed that the costs, risks and benefits influenced choices as well. For example, Altmann et al. [6] reviewed 24 studies on preferences for clean vehicles and fuels (the majority concerned electric vehicles) and Molin et al. [30] studied preferences for alternatively fueled cars (biodiesel vehicles, hybrid vehicles and hydrogen vehicles). These studies showed that the indicated price and performance of the vehicle were the most important attributes influencing the preference for a vehicle. Lower vehicle emissions (e.g., CO_2) had only a minor or even no influence on preferences. These studies also showed that convenience factors, including battery charging time, the range of the vehicle (the distance a vehicle can drive on a full tank or battery), and the detour needed to reach a refueling station influenced people's preferences considerably. The convenience factors can be considered to reflect a cost of the technology.

3.2. Normative motives and norm activation theory

Normative motives are a key factor in Schwartz's norm activation model [41,40]. Schwartz emphasizes that pro-social behavior, that is, behavior that benefits others, results from feelings of moral obligations to perform or refrain from specific actions (p.191 [42]) as reflected in personal norms. These personal norms are activated when people are aware of adverse consequences of not acting in a socially desirable way, and when they feel they can do something to mitigate these problems (as reflected in outcome efficacy). The norm activation theory has been applied to technology acceptance: acceptance of nuclear energy use [9]. De Groot and Steg [9] found that people were more willing to protest against nuclear power when they felt morally obliged to do so (and thus had stronger personal norms to protest). Personal norms were stronger when people thought that nuclear power had many risks and costs, and few benefits. The norm activation model was less predictive of willingness to take action in favor of nuclear power, indicating that a moral framework is more predictive of behavior against than in favor of a new technology.

Related to sustainable energy technology acceptance, we suggest that awareness of adverse consequences refers to awareness of problems related to the current energy system when no new energy technology is implemented and used. These problems include environmental effects such as air pollution, noise pollution, climate change, and loss of biodiversity, and social effects such as scarcity of energy sources and increasing energy costs which can affect safety and well-being. We refer to this as problem perception. We propose that personal norms will depend on problem perception, and the perceived costs, risks and benefits of a particular energy technology.

Outcome efficacy reflects the extent to which one can contribute to effective solutions to the problem [50]. Related to technology acceptance, two types of outcome efficacy are relevant. First, whether one thinks that the new technology will actually reduce

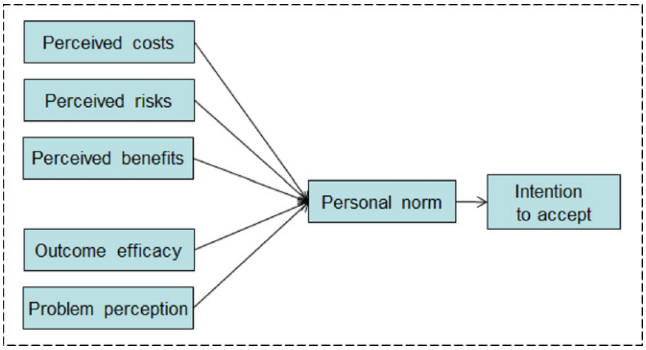

Fig. 2. Norm-related factors influencing intention to accept via personal norm.

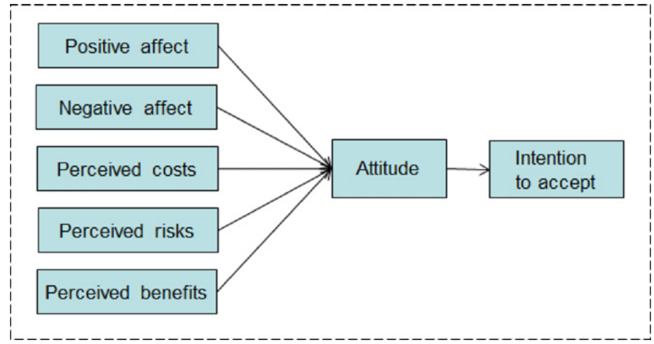

Fig. 3. The combined effect of affect and cognitions influencing intention to accept via attitude.

energy problems. Second, the extent to which a person thinks that behavior in favor or against the technology will influence the actual implementation of the technology. The latter is more relevant for citizen acceptance than for consumer acceptance, because for citizen acceptance others generally decide on the implementation of the technology and the amount of public influence on such decisions is uncertain. The first type of outcome efficacy seems equally relevant for both citizen and consumer acceptance. Outcome efficacy influences intention to accept via personal norm.

From empirical research it can thus be concluded that problem perception and outcome efficacy influence personal norm and indirectly intention to accept [50] and perceived costs, risks and benefits can be an additional predictor for personal for energy technology acceptance situations [9]. No study has studied whether problem perception and perceived costs, risks and benefits all uniquely contribute to predict personal norm. Possibly, in some cases problem perception influences personal norm via perceived benefits of the technology. For example, the more severe one thinks the climate change problem is, the more one might think that a technology that reduces CO_2-emissions is beneficial for the environment, the more positively one evaluates the technology and the more positively one evaluates behavior in favor of the technology. Limiting ourselves to results from available empirical studies, we now choose to include all predictors for personal norm in the model. See Fig. 2.

3.3. Hedonic motives and studies on affect

Various psychological studies have examined affective responses influencing attitudes and behavior [26], for example in the field of risk perception [52] and marketing [15]. Affect may directly influence attitudes [3] and, following the theory of planned behavior, therefore indirectly influences intention to behave. This suggests that attitudes are rooted in both perceived costs, risks and benefits (cognitions) and affect [3], and that attitudes can be defined as "an evaluative integration of cognitions and affects experienced in relation to an object" [7]. Affects can concern expected feelings, resulting from the outcome of decisions [26], or affect when thinking about the technology [28]. Lavine et al. [23] even showed that when cognitions and affect point in the same direction (e.g., are both positive or both negative), they equally contribute to attitude, but when they contradict, then feelings tend to dominate over cognitions in the formation of attitudes. This shows the importance of including both cognitions and affects as antecedents for attitudes.

Empirical studies [28,8,36] have shown that positive affect (such as pride, happiness, satisfaction) and negative affect (such as fear, worries, anger) are related but distinct factors, and that both factors independently predict attitudes. For energy technology acceptance, affect was found to influence evaluations of nuclear power plants [35], carbon capture and storage [28], and hydrogen technology [32]. We propose that positive and negative affect, together with perceived costs, risks and benefits influence attitudes and indirectly intentions (Fig. 3).

4. The effect of the perceived context: trust and fairness

Not only the evaluation of technology itself, but also the way it is implemented (e.g., by whom, via which procedures, at which location) may influence acceptance. Below, we discuss the effect of trust, procedural fairness and distributive fairness.

4.1. Trust

When people know little about a technology, acceptance may mostly depend on trust in actors that are responsible for the technology, as a heuristic or alternative ground to base one's opinion on [28,48]. As yet, no agreement exists about the exact definition of trust and types of trust [47]. A popular definition was proposed by Rousseau et al. [37]: "Trust is a psychological state comprising the intention to accept vulnerability based upon positive expectations of the intentions or behavior of another" (p. 395).

Trust in actors who are responsible for the technology (such as regulators or owners of the technology) have been found to influence citizen's perception of the risks and benefits of the relevant technology, and their affective responses towards risky technologies, such as gene technology [45,46], nano technology [49], nuclear power [48], hydrogen technologies [32], and carbon capture and storage [28]; trust in actors that are responsible for the technology generally increases acceptance. Trust in other parties than those responsible for the technology can possibly decrease acceptance, if those trusted parties are against the technology.

In most studies, trust affected acceptability or intention to accept indirectly via perceived costs risks and benefits. For example, higher trust in those responsible for the technology and proclaiming the technology would lead to higher perceived benefits and lower perceived costs and risks, which in turn would lead to a higher acceptability and intention to accept. However, two studies modeled trust also as a direct antecedent of intentions to accept [49,53]. Three studies suggested that trust leads to affect and via affect influences perceived risks and benefits [28,32,49], meaning that trust would result in a more positive feeling, which would then result in a more positive evaluation of costs, risks and benefits. Following the most commonly modeled paths, we modeled a direct path from trust to positive affect, negative affect and perceived costs, risks and benefits. See Fig. 4. Further research should further clarify and strengthen assumptions about causality between factors.

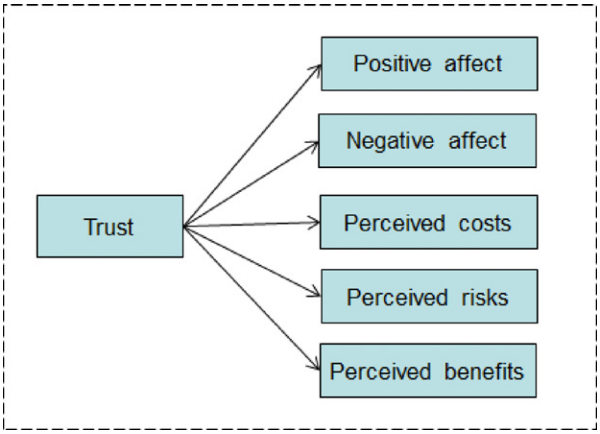

Fig. 4. The effect of trust on positive and negative affect, and perceived costs, risks and benefits.

4.2. Fairness

How people evaluate a specific technology or policy implementation and how they will respond to this is influenced by the perceived fairness of the decision process that led to implementation and perceived fairness of the distribution of costs, risks, and benefits resulting from the specific implementation; increased fairness will lead to increased acceptability and acceptance. While the former type of fairness is called procedural fairness, the latter type is called distributive fairness. Evidence is found, among others, for wind power farms [19,56] and travel demand management [16,22,39].

Procedures are considered to be less fair when people or interest groups have no voice in the decision process [24,54]. Earle and Siegrist [13] conclude in the context of environmental risk management that "judgments of fairness can lead to trust when fairness is the dominant value or when no other trust-relevant information is available but, more often, trust leads to perceived fairness". Following this, we assume that trust and procedural fairness are influencing each other.

For distributive fairness, several types have been distinguished [39,24]. In a study on acceptability of transport pricing policies, Schuitema et al. [39] distinguished 6 types of distributive fairness. They concluded that fairness principles based on collective outcomes (distribution between groups) more strongly influenced acceptability of travel demand management strategies than fairness principals related to personal outcomes. Like travel demand management, the distribution of collective outcomes might play an important role for citizen acceptance.

Schuitema et al. [39] showed that distributive fairness predicted attitudes towards the travel demand measures. Wolsink [56] modeled distributive fairness as a direct predictor or intention to accept. Two studies that used a general fairness measure, rather than focusing on a type of procedural or distributive fairness [16,22] also modeled fairness as a predictor of attitudes towards travel demand management. Following most of these studies, we assume that procedural and distributive fairness influence attitudes directly and intentions indirectly. See Fig. 5.

Procedural and distributive fairness mainly play a role when decisions are made by others and citizens living near to the location of the implementation and use of the technology feel affected by the way the technology is implemented and used (e.g., the location, the rate of use of the technology); these factors are thus of importance for citizen acceptance and will have little influence on consumer acceptance.

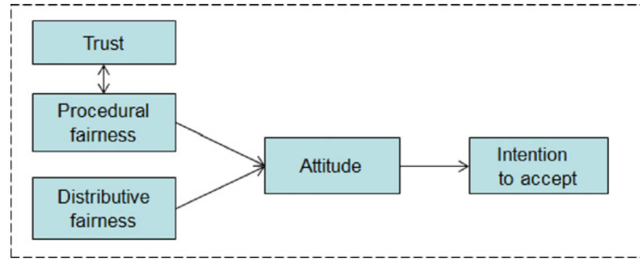

Fig. 5. The effect of procedural and distributive fairness on attitude and the interaction of procedural fairness with trust.

5. The effect of knowledge and experience

Knowledge of and experience with the technology can influence how people evaluate the technology. We will discuss both factors.

5.1. Knowledge

Knowledge, for example about how the technology works, and the effects of the technology, can influence people's perception of the costs, risks and benefits of a technology and indirectly the acceptability and acceptance of a technology. For example, Molin [29] showed that people with more knowledge on hydrogen as a fuel perceived less safety risks, which was related to a less positive attitude towards using hydrogen as a fuel and willingness to use hydrogen fueled technologies. However, people with less knowledge on hydrogen as a fuel also perceived more perceived environmental benefits of hydrogen use, which indirectly lead to a more positive attitude and willingness to use. Since the effect of increase perceived environmental benefits was stronger than the effect of increase perceived safety risks in this case, the combined effects of knowledge via both beliefs resulted in a positive effect on attitude and willingness to use. Correlations between knowledge of a technology and acceptance of the technology have been studied more widely. For hydrogen technology acceptance, mainly positive effects of knowledge on acceptance have been found [1,33,34]. For carbon capture and storage, a survey in China [10] also found a positive effect of knowledge (as rated by the participant) on acceptance. For wind power acceptance, Ellis et al. [14] found little evidence of a relation between knowledge of wind power and its acceptance. Since most of these studies were questionnaire studies and only employed correlational analyses, the causal directions between knowledge and acceptance has not been empirically established; possibly knowledge influences acceptance, however, acceptance may also influence information uptake and thus indirectly knowledge.

Knowledge can also change the base of people's opinions. Siegrist and Cvetkovich [48] showed that the higher the self-rated knowledge level for a hazardous technology is, the stronger the (negative) correlation between trust in those who manage the technology and perceived risk of the technology is. The same was found for the trust-perceived benefit relation (a stronger positive correlation). Knowledge thus has direct and indirect effects on acceptance, and moderating effects on the effects of antecedents on acceptance. To capture all possible effects of knowledge, we pictured knowledge to influence all variables in our conceptual model (see Fig. 6).

House et al. [20] made a distinction between objective knowledge, measured in a knowledge test, and subjective knowledge, as rated by participants. The average correlation between the two knowledge items in their study was limited (it amounted to 0.36), which indicates that self-rated knowledge is rather different from knowledge as measured in knowledge tests. They also found that intentions to accept GM food products were influenced

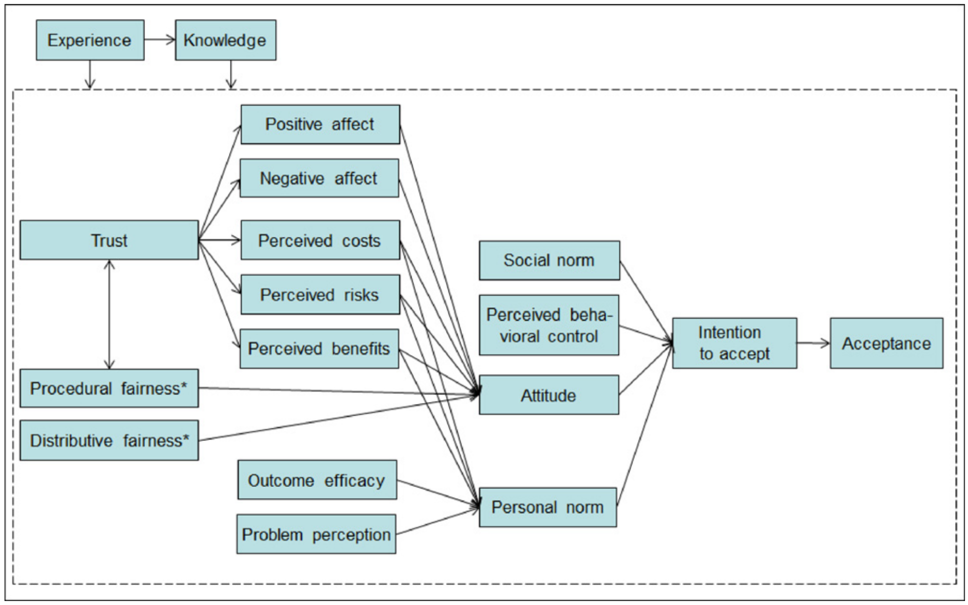

Fig. 6. A schematic representation of the technology acceptance framework. *Note that the two fairness types are mainly relevant for citizen acceptance.

by subjective knowledge but not by objective knowledge. Likewise, subjective knowledge about an energy technology can have a different effect on acceptance than objective knowledge on the energy technology and studies should thus distinguish these types of knowledge and their effects.

5.2. Experience with the technology

Experience is related to knowledge, because experience can increase knowledge. Experience can also influence perceived costs, risks and benefits. Schuitema et al. [39], for example, found that people became more positive about the costs and benefits of the congestion charge (a pricing policy measure) in Stockholm, after it's implementation. Three hydrogen acceptance studies also illustrated effects of experience with hydrogen technology acceptance on perceived costs, risks and benefits: A study in California with potential early adopters [27] showed that after a ride and drive clinic with hydrogen vehicles, the hydrogen vehicles were perceived as more safe and having a better performance than beforehand. Another study in California and Michigan [44] tested attitude change of employees that gained experience with a company hydrogen fuel-cell vehicle. At the end of the test project, more people stated that they felt equally safe with the hydrogen vehicle as with a gasoline vehicle than at the beginning. A study testing the effect of a one year experience with a hydrogen bus project [38] showed that people evaluated the technology in the buses as slightly safer.

Experience can also influence how people weigh factors to come to an opinion or to intention to behave. Schuitema et al. [39], for example found that before the introduction of the congestion charge, expected increase in travel costs influenced acceptability, while after the introduction of the travel charge, perceived travel costs did not influence acceptability. For information technologies, Venkatesh et al. [55] furthermore found that experience with a new information technology (e.g., software) in companies influenced the strength of the effects of effort expectancy (which can be considered a perceived cost), social influence (social norm) and facilitating condition (which is similar to perceived behavioral control) on intention to use the new information technology. We conclude that experience can have a direct effect on variables in the model, but can also have moderating effects on the relationships in the model. We depicted this extensive effect of experience with the technology as an arrow that points at all variables in our conceptual model, rather than to specific factors and relations. See Fig. 6.

6. The comprehensive acceptance framework

Based on the theories and empirical evidence discussed above, we propose the comprehensive technology acceptance framework as depicted in Fig. 6.

7. Discussion and conclusion

In this paper, we proposed a technology acceptance framework to understand citizen and consumer acceptance of new energy technologies, based on psychological theories and findings from technology acceptance studies. The model is specifically composed for sustainable energy technologies, such as wind mills, carbon capture and storage, and hydrogen technology, but may also be used as a framework to study the acceptance of other technologies that have social or environmental benefits and that have potential risks and costs. Examples of such technologies are gene technology, electro-magnetic radiation from UMTS towers, and nanotechnology.

We limited the model in this paper to psychological factors. Other factors may affect technology acceptance as well, such as individual traits (e.g., values, worldviews and socio-demographic variables) and situational factors (proposed location of the technology, media attention, oil prices, etc.). These factors will likely influence acceptability and acceptance through the variables in the framework, rather than directly, and the model can be used to identify through which variables these factors influence acceptability and acceptance.

The causal order of the variables in the model has been subject of debate in several studies. The framework as it is depicted is based on relationships that we consider dominantly suggested and tested in literature. Proper research designs need to be used to clarify or fortify assumptions on causality, such as experimental and longitudinal designs.

All variables in the framework have been widely corroborated as relevant for behavior and/or technology acceptance and are

recommended to be used in more comprehensive acceptance studies. We hope this framework will contribute to clarifying the relative importance of the variables for sustainable energy technology acceptance.

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Further reading

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